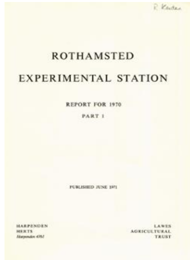
ROTHAMSTED RESEARCH

# Report for 1970 - Part1


ROTHAMSTED

EXPERIMENTAL STATION

REPORT FOR 1970

PART 1



## Chemistry Department

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G. W. Cooke (1971) *Chemistry Department* ; Report For 1970 - Part1, pp 36 - 63 **- DOI: https://doi.org/10.23637/ERADOC-1-125**

# CHEMISTRY DEPARTMENT

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### Practical implications of the 1970 work

The standard manuring recommended for maincrop potatoes grown on sandy loam soil, such as at Woburn, is 2·0 cwt N, 1·3 cwt $P_2O_5$ and 2·0 cwt $K_2O$ per acre. Our recent experiments there showed twice as much fertiliser was justified *provided* the dressings were incorporated deeply. There was little gain from more than 2 cwt N, 3 cwt $P_2O_5$ and 3 cwt $K_2O$/acre when it was worked shallowly into the seedbed, but twice as much worked deeply into the soil increased yield by 5 tons/acre. Whether the effects at Woburn will repeat on other potato soils has yet to be tested.

We continue to find small but consistent advantages from special methods of fertilising barley; 0·25 cwt/acre each of $P_2O_5$ and $K_2O$ when broadcast increased grain yield by only 0·5 cwt but by 2·8 cwt when combine-drilled. Mean yields were largest with PK combine-drilled and N *injected* into the soil as aqueous ammonia, exceeding those with a combine-drilled granular NPK fertiliser. All three nutrients broadcast together in a granular fertiliser, or sprayed as liquid fertiliser on the soil, have never given the largest yields obtained during the three years of these comparisons.

Aqueous solutions of ammonia or urea gave the same yields of grass as a single dressing of solid ammonium nitrate, whereas anhydrous ammonia again gave less. Divided dressings of solid fertiliser gave more grass than single dressings of injected liquids; even in this dry summer injecting N below the surface had no advantage.

Compound fertilisers have roughly doubled in concentration in 25 years as ammonium nitrate, urea and ammonium phosphates have replaced more dilute materials. Using concentrated compounds cheapens costs of both carriage and application, but the upper limit with the ingredients now used in Britain is nearly reached (many compounds contain 50% or more of N + $P_2O_5$ + $K_2O$). More concentrated fertilisers become possible by using condensed phosphates (such as the potassium 'metaphosphate' we have tested), and still more by linking N and P chemically in the unusual substances we began to test this year and found were efficient fertilisers.

The long-term experiments in which we value phosphate residues show that it is false economy to use minimal dressings of phosphate because any surplus accumulates in soil and can greatly benefit later crops. For example, barley this year yielded 6 cwt/acre more grain where larger annual dressings than the generally recommended 0·3 cwt $P_2O_5$/acre have been given in the past (or where a much larger dose was given 3 years ago). Barley grain yields were increased by about 0·11 cwt/acre for an extra part per million of phosphorus soluble in sodium bicarbonate solution. The accumulation of P in our arable soils could be responsible for a fifth or more of the increase in barley yields during the last quarter century.

At Woburn, as on much light land lack of lime and Mg can limit yields of sugar beet. Dolomite is best for acid Mg-deficient soils because it supplies both lime and available Mg and is much cheaper than magnesite or epsom salt. Heart rot of sugar beet also occurs there and boron may be needed as a routine fertiliser. Not only yield, but also quality of crops grown on light soils can be affected by nutrient deficiencies. Magnesium fertiliser greatly increased the amounts of soluble carbohydrates in oats grown on acid podzolic soil from Dorset and diminished the fraction of the total nitrogen that was not true protein. Experiments at Woburn also show that for grass to convert large dressings



https://doi.org/10.23637/ERADOC-1-125 

of fertiliser-N to protein and to produce maximum amount of carbohydrates, potassium and/or sodium are needed.

Simazine used to control weeds in beans can damage the crop on soil poor in organic matter. In this very dry summer, residues of previous dressings were more damaging than fresh dressings, which were not washed down to the roots.

Experiments with wheat, barley and grass, sprayed with herbicide and liquid nitrogen fertiliser, showed that although liquid was often inferior to 'Nitro-Chalk' as a nitrogen fertiliser, there was no loss of yield from applying it with herbicide, and weed control was sometimes improved by doing so.

## Experiments on nitrogen fertilisers

**Ammonia and other N fertiliser for cut grass.** An experiment on permanent grassland at Rothamsted compared yields from anhydrous (82% N) and aqueous (25% N) ammonia and from an aqueous solution (18% N) of urea (injected in bands 12 in. apart and 4 in. deep in March), with yields from equivalent amounts of ammonium nitrate ('Nitro-Chalk 21'), broadcast either all at once (in March), or divided equally for each of three cuttings (in June, August and October). The anhydrous ammonia applicator was unsatisfactory at first and had to be repaired—consequently the anhydrous ammonia was applied three weeks later than the other N fertilisers; yields were smaller than from single dressings of ammonium nitrate at the first two cuttings, but a little larger at the final one, so the total (Table 1) was smaller. By contrast, aqueous ammonia and urea were each more effective than a single dressing of ammonium nitrate at the first cutting, but slightly less at the second and third cuttings; all three gave similar total yields, except with 4·0 cwt N/acre, when aqueous ammonia gave the largest yield. As previously, divided dressings of ammonium nitrate were more effective than single dressings; divided dressings of 2·0 cwt N/acre gave 76·3 cwt dry grass/acre, 10 cwt/acre more than with a single dressing, and there was no benefit from giving more. So, even in this dry summer, injecting N had little or no advantage over applying it to the soil surface.

**TABLE 1**

*Comparisons of anhydrous and aqueous ammonia and urea with ammonium nitrate as 'Nitro-Chalk' for grass*

Yields of dry grass (cwt/acre)
Total yield without nitrogen 41·9

| N applied cwt/acre | Ammonia: Anhydrous* | Ammonia: Aqueous | Urea | 'Nitro-Chalk': Single | 'Nitro-Chalk': Divided |
|---|---|---|---|---|---|
| 1 | (55·0) | 57·5 | 55·0 | 59·4 | 64·4 |
| 2 | (61·7) | 65·9 | 70·4 | 66·1 | 76·3 |
| 3 | (70·3) | 71·4 | 73·1 | 72·4 | 76·9 |
| 4 | (68·7) | 79·5 | 69·7 | 69·5 | 76·4 |

Standard error ±2·57

* Excluded from statistical analysis

**Aqueous ammonia for grazed grass.** In the experiment, begun in 1969, aqueous ammonia was again injected during March (at 1·0, 2·0, 3·0 and 4·0 cwt N/acre) and the yields (under cages) were compared with those from equivalent dressings of ammonium nitrate ('Nitro-Chalk 21') divided equally between each of six cuttings. At the first three cuttings (May, June and July), aqueous ammonia gave yields as large as, or larger than, from ammonium nitrate, but not at the last three. Giving more than 3·0 cwt N/acre in either



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form did not increase yield and at this amount ammonium nitrate gave a slightly larger total yield.

**Liquid fertilisers for barley.** Five experiments continued those begun in 1968: three were on light loams overlying Chalk, one on Clay-with-Flints and one on a sandy loam overlying Lower Greensand. In each:

1. N was either injected into the seedbed in bands 12 in. apart and 4 in. deep just before sowing, or broadcast over the seedbed.
2. NPK compound fertilisers, both liquid and granular, were either combine-drilled or applied to the soil surface.

N significantly increased yields in each, P and K in two. Table 2 shows that, as in 1969, injected N (either as aqueous ammonia or as urea) gave larger yields than did ammonium nitrate broadcast over the seedbed. Also, there was a small benefit from the combine-drilled 'starter dose' of N (applied in 6-15-15 compound fertiliser).

**TABLE 2**

*Mean yields of spring barley from five experiments with N and NPK fertilisers in 1970*

Yields of grain at 15% moisture content (cwt/acre)
Without fertiliser 19·4

| Fertilisers tested | Fertilisers applied to give 0·5 cwt N/acre | Fertilisers applied to give 1·0 cwt N/acre |
|---|---|---|
| Broadcast 'Nitro-Chalk' | 30·5 | 31·7 |
| Broadcast 'Nitro-Chalk' + drilled 0–20–20 | 31·2 | 33·5 |
| Injected aqueous ammonia + drilled 0–20–20 | 32·2 | 34·9 |
| Injected aqueous ammonia + drilled 6–15–15 | 33·0 | 36·2 |
| Injected solution of urea + drilled 0–20–20 | 32·4 | 36·0 |
| Broadcast granular 20–10–10 | 29·5 | 33·0 |
| Drilled granular 20–10–10 | 31·2 | 34·1 |
| Sprayed liquid 14–6–8 | 29·4 | 33·3 |
| Drilled liquid 14–6–8 | 31·9 | 35·1 |

So much rain fell after the barley was sown that combine-drilling the double amount of fertiliser, even as a liquid, did not check growth, and in contrast to 1968 and 1969, both amounts of granular or liquid NPK fertiliser gave larger yields when drilled than when broadcast or sprayed.

From 1968–70 we made 14 experiments in which N, $P_2O_5$ and $K_2O$ were applied in a 2 : 1 : 1 ratio. Mean responses to the two amounts of $P_2O_5$ and $K_2O$ given (either 0·25 or 0·50 cwt/acre of each, with 0·50 and 1·00 cwt N/acre respectively) were 0·4 and 2·8 cwt/acre when they were broadcast, and 2·9 and 3·6 cwt/acre when they were combine-drilled, with the N always broadcast.

The largest mean yields came from injecting either aqueous ammonia (with or without the starter dose of N) or urea. Also, one of these three treatments gave the largest mean yields in 12 of the 14 experiments, so that injection was a consistently satisfactory method of applying N. The fact that yields from aqueous ammonia and urea were nearly the same (and both larger than from 'Nitro-Chalk') suggests: (i) that little of the injected ammonia was lost to the atmosphere; (ii) that the urea soon hydrolysed and then behaved as ammonia. By contrast, either broadcasting the granular, or spraying the liquid NPK fertiliser, never produced yields in the top three placings in any experiment; nor did giving nitrogen alone. Combine-drilling these two NPK compounds gave intermediate



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results, because the double amount (especially of the liquid) often checked early growth. The results not only confirmed that it is unwise to combine-drill large amounts of granular fertilisers, but also showed that risks with liquids (based on urea and diammonium phosphate) are even greater. (Widdowson, Penny and Flint)

**Anhydrous ammonia**

***Spacings between injections.*** Ryegrass, sown the previous autumn in rows 4·75 in. apart, was cut with a rotary mower in spring 1970 before injecting ammonia by hand or applying 'Nitro-Chalk'. Ammonia was injected every row, alternate rows or every third row, either within the row or between the rows of grass. The area per injection was constant at 42·75 in.$^2$, and the distances between injections along the rows were 9 in., 4·5 in. and 3 in. for 1, 2 and 3 row injections respectively. 'Nitro-Chalk' was applied either as one dressing during spring, or half the amount during spring and a quarter after the first and second cuts of grass. Both fertilisers supplied 400 lb N/acre.

***Whole plot yields.*** Grass given 'Nitro-Chalk' yielded most dry matter containing most N at the first cut. During the dry weather that followed, the grass yielded more and took up more N from ammonia injected than from 'Nitro-Chalk' broadcast. The final cut measured residual effects; yield with the divided dressing of 'Nitro-Chalk' was larger, and the grass contained more N, than with ammonia; the single dressing of 'Nitro-Chalk' produced least.

***Total yields.*** Total yields during the season were most from ammonia injected either into or between every row 9 in. apart and least from ammonia injected *into* either alternate rows or every third row of grass and from the single dressing of 'Nitro-Chalk'. Most N was taken up from the divided dressing of 'Nitro-Chalk' and least from ammonia injected into alternate rows or every third row, whether within or between rows.

***Damage by injecting into rows.*** Injecting ammonia into alternate rows, or every third row, damaged grass within the row so it produced less dry matter and took up less N than grass in rows not injected. With ammonia injected *between* every third row, the rows adjacent to the injection produced more dry matter and took up more N than the more distant row. (Gasser, Flint and Penny)

**Reactions between ammonia and soil.** Further adsorption isotherms (the quantity of ammonia gas adsorbed by dry soil at a particular pressure of ammonia gas) were measured and all were apparently Type II of Brunauer's classification (Brunauer (1943) *The adsorption of gases and vapours*, Vol. I, Princeton University Press); most were reproducible up to relative pressure $p/p_0 = 0{\cdot}1$ ($p = ca$ 1 atmosphere at 25°, $p_0$ = saturation vapour pressure of ammonia). One soil rich in organic matter gave a less reproducible isotherm because ammonia was slowly adsorbed at $p/p_0 > 0{\cdot}02$. A sample of Wyoming bentonite gave an S-shaped isotherm and equilibrated more slowly than any of the soils studied.

In contrast to published results for adsorption of water by soils, B.E.T. plots (*see* Brunauer (1943) above) based on the ammonia isotherms were not linear, perhaps because the B.E.T. equation applies best at slightly larger relative pressures than those used.

Two samples of Barnfield soil differing in organic-matter content (one with 0·75% C and the other with 2·74% C) had different adsorption isotherms in the range $p/p_0 = 0{\cdot}01$ to 0·1 but this was not so after they were treated with hydrogen peroxide.



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**Heats of adsorption.** Although organic matter has been implicated in fixing anhydrous ammonia, the above results indicate that initial adsorption takes place on other, more reactive, sites. Equipment was made to measure heats of adsorption, especially in the relative pressure range 0 to 0·02 where reaction is fastest, and a provisional figure of $75 \pm 10$ kJ mol$^{-1}$ can be reported for the initial heat of adsorption of ammonia gas on Geescroft soil (whole soil; pH 5·3 in 0·01*M* $CaCl_2$, organic carbon 1·98% by a modified Tinsley method). This is close to the figure reported for adsorption of ammonia on the surface hydroxyl groups of silica gel, and indicates strong chemical interaction.

**Displacement of exchangeable cations by ammonia.** In aqueous ammonia pH is higher than 10 and the equilibrium in $NH_3 + H_2O = NH_4^+ + OH^-$ lies to the left, favouring $NH_3$ almost entirely; when exchange occurs between $NH_4^+$ and soil cations the equilibrium moves to the right. If the exchangeable cations are $Na^+$ or $K^+$ the hydroxides and carbonates are both soluble and any displaced $Na^+$ or $K^+$ can be measured and the amount of $OH^-$ released can be titrated. Exchangeable $Mg^{2+}$ or $Ca^{2+}$ ions are removed from solution by precipitation as hydroxide or carbonate respectively at pH $> 10$ and the changes in $OH^-$ concentrations are too small to measure by titration.

Cation-saturated soil samples were shaken briefly in stoppered tubes with 0·03*M* aqueous ammonia and after 24 hours at 22° most of the liquid was withdrawn and centrifuged. The amount of $Na^+$ or $K^+$ released into ammonia solution was measured spectrophotometrically (a blank correction was made using water). The results are compared below with the amount of $OH^-$ released through ion-exchange, measured by titrating the $NH_3$ steam distilled from a portion of solution into excess HCl, and by titrating a duplicate portion without steam distilling:

| Exchangeable cation | Ammonia adsorbed: Total | Ammonia adsorbed: By ion exchange | Cation released |
|---|---|---|---|
| | meq. per 100 g soil | | |
| K | 4·5 | 0·7 | 1·0 |
| Na | 6·4 | 4·2 | 6·8 |
| Ca | 7·0 | not measured | |
| Mg | 10·0 | not measured | |

The total ammonia adsorbed depends markedly on the exchangeable cation; the $Mg^{2+}$-saturated soil adsorbs twice the amount adsorbed by the $K^+$-saturated soil.

The contribution from the ion-exchange mechanism varies also, the figures indicating that this mechanism accounts for little of the total adsorption by $K^+$-saturated soil (similar results have been obtained for two other $K^+$-saturated arable soils). This soil therefore adsorbs ammonia chiefly by other means (possibly by direct co-ordination of acid sites, as defined by G. N. Lewis, or by protonation on sites active at high pH).

The exchange mechanism accounts for most of the ammonia adsorbed by the $Na^+$-saturated soil, consistent with the generally observed ease of exchange of $Na^+$ compared with $K^+$. Exchange of $Mg^{2+}$ and $Ca^{2+}$ is favoured because these ions are removed from the equilibrium involved by precipitation; it is unlikely that direct ammination of the cation could be partly responsible for the larger adsorption in these cases. (Ashworth)

**Isobutylidene diurea (IBDU) in forest nurseries.** This granulated slow-acting nitrogen fertiliser (29·5–32·0%N), made in Japan, was tested with seedlings and transplants of Sitka spruce (*Picea sitchensis*) on a very sandy podsol (Wareham) and a sandy loam (Kennington). Three compounds—two particle sizes of IBDU (0·8–1·5 and 1·5–2·4 mm)



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and formalised casein (already shown to be a good source of slow-acting N)—were applied before sowing or transplanting, and compared with four top-dressings of 'Nitro-Chalk' and with no N. Four amounts of each fertiliser were tested; all plots were given basal P, K and Mg. The experiments with seedlings lasted four years, those with transplants three; all ended in 1969.

**TABLE 3**

*Comparison of pre-sowing or pre-transplanting application of IBDU (medium and coarse) and formalised casein with four top-dressings of 'Nitro-Chalk' for Sitka spruce*

| | Height (cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Seedlings | | | | | Transplants | |
| | Wareham | | | | Kennington | Wareham | Kennington |
| | 1966 | 1967 | 1968 | 1969 | 1966–69 | 1967–69 | 1967–69 |
| Without N | 1·0 | 0·9 | 1·1 | 1·7 | 3·3 | 13·0 | 25·8 |
| *Increases from* | | | | | | | |
| IBDU (0·8–1·5) | 4·4 | 2·0 | 2·1 | 0·6 | 2·2 | 10·4 | 8·3 |
| IBDU (1·5–2·4) | 5·1 | 3·0 | 2·0 | 0·9 | 2·8 | 10·8 | 8·5 |
| Form. casein | 4·4 | 3·6 | 4·9 | 3·7 | 2·8 | 11·7 | 9·6 |
| 'Nitro-Chalk' | 5·1 | 5·2 | 6·4 | 4·2 | 3·8 | 11·0 | 9·8 |
| S.E. ± of increases | 0·28 | 0·45 | 0·39 | 0·25 | 0·23 | 0·84 | 0·45 |

Table 3 shows responses to 'Nitro-Chalk' were large, especially in wet seasons. Formalised casein again proved a good source of slow-release N under all conditions tested—almost equivalent in effectiveness to four separate top-dressings of 'Nitro-Chalk'. IBDU (especially the coarse fraction) was equally efficient for transplants at both nurseries and was safe up to the largest dressing tested (280 kg N/ha). It was also as good as formalised casein for seedbeds on the loamy sand at Kennington, but after a promising start (*Rothamsted Report for 1966*, 44), it became steadily less effective at Wareham. No satisfactory reason can be offered for this decline; it is not because IBDU failed to decompose, because analyses of soil at the end of the experiment, and results from associated pot experiments with ryegrass, showed that nitrogen had not accumulated. There was no evidence of consistent temperature or rainfall changes with years to aggravate leaching. The soil became increasingly more acid during the first three years, but liming to near optimum (pH 4·5 in $CaCl_2$) for Sitka spruce at the beginning of the last season did not improve the efficiency of IBDU. There were no indications that the seedlings were harmed: germination was not retarded, plant numbers were as in other plots, and seedlings usually grew better with the large than with the small dressings—never the reverse. (Benzian, Freeman and Mitchell)

**Glycoluril as a fertiliser.** Glycoluril (hexahydro-2,5-dioxoimidazol-[4,5,*d*]-imidazole), formed by the condensation of two molecules of urea with one molecule of glyoxal, contains 39·4% N, and is a potential slow-acting N fertiliser. It was prepared as a powder and as granules of 2–3 mm diameter. Increasing amounts up to 1000 ppm of N as glycoluril powder were mixed with soil and its decomposition tested in the laboratory. Six soils were used, from Rothamsted (slightly acid clay loam), Woburn (neutral sandy loam), Saxmundham (sandy clay), and three calcareous loams from Broom's Barn. Soils were incubated at 50% water-holding capacity and analysed after 1, 2, 4, 8, 16, 24 and 32 weeks.

On average of the six soils, more of the added N was recovered as mineral-N from the smallest amount added than from others.



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| | Glycoluril added, ppm N | | | | |
|---|---|---|---|---|---|
| | 200 | 400 | 600 | 800 | 1000 |
| % of N applied found as mineral-N | 88 | 80 | 81 | 80 | 78 |

On average of amounts applied, most N was recovered from the Rothamsted clay loam (85%) and least from the Saxmundham sandy clay (78%). Individual recoveries ranged from 71% (400 ppm N to Saxmundham soil) to 94% (200 ppm N to Rothamsted soil). There was a delay of from 1 to 4 weeks in all soils before glycoluril decomposed rapidly. With 200 ppm N decomposition was complete in 12–16 weeks, with 1000 ppm N in 16–32 weeks. (Gasser)

**Pot experiment.** Grass was grown in the glasshouse in the same six soils. Fertiliser-N was applied as ammonium sulphate, glycoluril as powder, or as granules 2–3 mm diameter all supplying 0·5 or 1·0 g N/pot. Grass was sown on 3 July 1969 and cut six times between August 1969 and February 1970. Yields and N uptake from glycoluril were much less than from ammonium sulphate at the first cut, but more at the second. Averaging the six soils and two amounts of fertiliser-N used, the total N recovered was 73% from ammonium sulphate, 60% from glycoluril powder and 59% from the granules. Glycoluril was four-fifths (81%) as good as ammonium sulphate, agreeing well with the amount of mineral-N measured in the laboratory. Yields and N uptakes at the first cut differed greatly between soils; the differences shown below (averaging two rates) reflected differences in damage to growth caused by ammonium sulphate and in the rates at which glycoluril decomposed:

| | | Per cent recovered of fertiliser-N applied as | | |
|---|---|---|---|---|
| | | | Glycoluril | |
| Place | Soil series | Ammonium sulphate | Powder | Granules 2–3 mm |
| Rothamsted | Batcombe | 64 | 30 | 23 |
| Saxmundham | Beccles | 60 | 28 | 17 |
| Woburn | Cottenham | 54 | 36 | 28 |
| Broom's Barn | Moulton | 37 | 6 | 5 |
| Broom's Barn | Newmarket | 24 | 10 | 8 |
| Broom's Barn | Stretham | 24 | 4 | 3 |

(Gasser and Mitchell)

**Very concentrated fertilisers.** Concentrated fertilisers are cheaper than others to carry and apply; examples of concentrated compounds are ammonium orthophosphates and polyphosphates. The concentration (of plant nutrients) in NP compounds is further increased by replacing OH in acid orthophosphates by $NH_2$, N and P being linked by co-valent bonds; using such substances as fertilisers offers the crop unusual groupings. G. Wanek (*Angew. Chem.* (1969), **81**, No. 15; *Nachr. Chem. Techn.* **17**, 260–262) tested several compounds containing NP covalent bonds, including amidophosphates, tri- and tetrameric phosphonitrilic amides and a metaphosphimate. Oats grown in pots yielded up to one-third more with the amidophosphates than with equivalent amounts of N and P as ammonium phosphate. S. E. Allen (*Phosphorus in Agriculture* (1970), No. 55, 25–35) who also tested several of these compounds, found that phosphoryl triamide and ammonium metaphosphimate were as good as superphosphate for supplying P to maize grown in pots.



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Salts of two amidophosphoric acids can be made; the tri-substituted compound is non-ionic. They were prepared as sodium salts for this work in the forms:

Sodium phosphoramidate: $O = P(OH)(ONa)(NH_2)$

Sodium phosphordiamidate hexahydrate: $O = P(ONa)(NH_2)(NH_2).6H_2O$

(covalent) Phosphoryl triamide: $O = P(NH_2)(NH_2)(NH_2)$

These were tested with barley and grass in experiments on West Barnfield (Rothamsted) and Stackyard Field (Woburn) and with grass in the glasshouse using soil from Geescroft (Rothamsted) and Stackyard (Woburn) fields. In the field, fertilisers supplied 10 or 20 lb P/acre; ammonium sulphate was added to the ammonium phosphate, and to mono- and di-amidophosphates to give the same N : P ratio as the phosphoryl triamide, so that 13·5 lb N/acre were added with 10 lb P/acre and 27 lb N/acre with 20 lb P/acre. Additional ammonium nitrate gave 100 lb N/acre for barley at Rothamsted and 150 lb N/acre for barley at Woburn; grass received 200 lb N/acre. All fertilisers were broadcast and raked into the surface before sowing seed; barley was sampled twice (during stem extension and after ear emergence), grass was cut in July and September. After good establishment, with all amidophosphates slightly improving early growth more than ammonium phosphate, there was little growth and some grass given extra N died back until rain fell in August.

Both grass experiments gave similar results without extra N, yields were slightly less from phosphoryl triamide than for the other NP fertilisers (Table 4); with extra N, yields were similar. Barley at Rothamsted responded to both N and P, at Woburn to N only. At both sites and both sampling times, yields with the various NP compounds and with additional N did not differ significantly. In the glasshouse grass yielded slightly less dry matter with phosphoryl triamide than with the other NP fertilisers. With extra N as ammonium sulphate (treated with the nitrification inhibitor, 'N-Serve'), yields did not differ between the forms of NP; on both soils, the grass given phosphoryl triamide contained less N than grass given ammonium phosphate, and the mean was significantly less. With N as sodium nitrate, yields and N uptake did not differ between forms.

**TABLE 4**

*Yields of ryegrass (lb/acre dry matter) without fertiliser-N and with various NP fertilisers with and without additional fertiliser-N*

Mean of Rothamsted and Woburn experiments

| | No extra N | With 200 lb N/acre |
|---|---|---|
| No fertiliser | 1240 | |
| Ammonium phosphate | 1860 | 3570 |
| Sodium phosphoramidate | 1890 | 3580 |
| Sodium phosphordiamidate | 2070 | 3650 |
| Phosphoryl triamide | 1680 | 3710 |



https://doi.org/10.23637/ERADOC-1-125 

These preliminary experiments are encouraging in showing that unusual compounds can be as efficient as conventional fertilisers and merit further study. (Gasser, Penny and Mitchell)

### Large amounts of fertiliser for potatoes at Woburn

The largest yields of potatoes on the Rothamsted and Woburn Reference Plots during the last 10 years came from giving fertiliser and farmyard manure (FYM) together and not fertilisers alone. This could be explained by: (i) inadequate manuring; (ii) placement effects (the FYM was dug down); (iii) interactions between FYM and fertilisers. These possibilities were examined at Woburn from 1968–70. In 1968 liquid fertiliser (with percentage composition N–$P_2O_5$–$K_2O$ of 7–7–10½) was injected by hand to give either 2·0 or 4·0 cwt N/acre in sidebands either 3 in. or 9 in. below the soil surface. The shallowly placed fertiliser greatly checked early growth, especially the double amount, but the deeply placed did not and the potatoes established early and grew uniformly, but matured early in September. The 1968 summer was dull and wet and the potatoes that had been badly checked by shallowly placed fertiliser continued to grow during September and finally produced the larger yields. Mean yields were increased from 20·4 to 22·3 tons/acre by the double amount of fertiliser.

In 1969 and 1970 tests were made both with FYM and with granular N and PK fertilisers supplying N, $P_2O_5$ and $K_2O$ in a 1 : 1½ : 1½ ratio. The fertilisers were applied to give 2·0 or 4·0 cwt N/acre and were either incorporated deeply (P and K dug down, N rotavated-in deeply) or worked shallowly into the final seedbed. The FYM (dug down) gave the same amounts of N as the fertiliser (and consequently less P, but more K). In both years the depth of incorporation was not important with the single amount of fertiliser, but was with the double amount, which needed to be incorporated deeply. With the double dressing, the deeply incorporated fertiliser gave mean yields of 25 tons/acre each year, 6·6 tons/acre more in 1969 (the potatoes were ridged-up immediately) and 3·8 tons/acre more in 1970 (when ridging was delayed for two weeks) than the shallow fertiliser.

Yields from FYM (17·5 or 35 tons/acre in 1969, 15 or 30 in 1970) were smaller than from fertiliser alone, but yields from FYM plus the single amount of fertiliser were always

**TABLE 5**

*Mean yields (tons/acre) of total tubers from two experiments at Woburn measuring effects of FYM and large amounts of granular fertiliser*

| | Fertiliser at | |
|---|---|---|
| | Single rate | Double rate |
| Cultivated in | | |
| All deeply | 20·6 | 25·0 |
| ½ deeply ½ shallowly | 20·7 | 22·3 |
| All shallowly | 19·4 | 19·8 |
| | **FYM at** | |
| | Single rate | Double rate |
| Without fertiliser | 13·4 | 15·7 |
| With fertiliser at single rate | 23·3 | 24·1 |

Single rate fertiliser supplied 2·0 cwt N, 3·0 cwt $P_2O_5$ and 3·0 cwt $K_2O$/acre
Double rate fertiliser supplied 4·0 cwt N, 6·0 cwt $P_2O_5$ and 6·0 cwt $K_2O$/acre
FYM at 16 or 32 tons/acre



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larger than with the single amount of fertiliser alone. However, the yield from the double amount of FYM plus the single amount of fertiliser was smaller in 1969, but larger in 1970, than from the double amount of deeply incorporated fertiliser, perhaps because the fertiliser given with the FYM was cultivated in shallowly in 1969 but deeply in 1970. Either amount of FYM plus the single amount of fertiliser was superior to either amount of shallowly incorporated fertiliser in both years (Table 5). (Widdowson and Penny)

### Rothamsted Reference Plots

**Arable experiments.** The experiment begun in 1956 (*Rothamsted Report for 1965*, 45) to measure the effects of N, P and K fertilisers and of FYM on five arable crops grown in rotation concluded its third cycle. The largest yields of potatoes and kale were obtained where both FYM and fertilisers were given. The mean yield (1966–70) of King Edward potatoes given the largest fertiliser dressing tested (1·2 cwt N, 0·5 cwt $P_2O_5$ and 2·0 cwt $K_2O$/acre) was 19·4 tons, but with 20 tons/acre of FYM also, the mean yield was 25·3 tons/acre. Similarly kale yielded 24·1 tons/acre with fertilisers alone (2·0 cwt N, 0·5 cwt $P_2O_5$ and 2·0 cwt $K_2O$/acre), but 29·5 tons/acre where FYM also was given. In 1966 Champlein winter wheat replaced Cappelle and Abed Deba spring barley replaced Proctor, to have varieties with stiffer straw. Previously the combination of FYM residues and of fertiliser caused both wheat and barley to lodge, and both yielded less grain than with fertiliser alone. Since 1966 lodging has been slight and the largest yields came from the combination of FYM and fertiliser. With wheat, maximum yield of grain increased only from 48·9 (in 1961–65) to 50·2 cwt/acre at 85% dry matter (in 1966–70), but with barley grain yields increased from 37·2 to 52·2 cwt/acre. By contrast, maximum yields from the ley were 10% smaller and of permanent grass no larger than before 1966.

The experiment also measures how the effects of N, P and K change with time. Although the effects of N and P were larger during the second cycle of crops than the first, they did not increase further in the third, in direct contrast with the effect of K which increased greatly in the third cycle. When examined by crops these trends were less consistent, especially for P and K. For example, although P affected the yields of wheat, barley and the ley a little less in the third than in the second cycle, its effects on potatoes and on kale increased with time. Evidently potatoes and kale best assess the soil-P status. Similarly, although K affected the yields of kale little throughout all three cycles, it had considerable and constant effects on barley and wheat, but these were small compared with those on the ley and potatoes, which also increased consistently with time. On average K was the most important nutrient for these crops and N the least. Mean effects in cwt dry matter/acre from 1966–70 (averaged over crops) were (1) 6·7 for N, (2) 12·5 for P, and (3) 23·9 for K.

**Experiments with grazed grass.** The experiment begun in 1959 ended (*Rothamsted Report for 1963*, 49). It measured the effects of N (as ammonium sulphate and as calcium nitrate) and of P and K on the yield of grass protected from stock for two months at a time by wire cages covering 1 sq yd. Yields taken from within the cages (from 1965–70) showed that the grass given N responded more to P than to K, but equally to each without N. Presumably the K encouraged the clover on the plots not given N. Calcium nitrate gave slightly larger yields than ammonium sulphate, even though lime was applied each winter to the ammonium sulphate plots. The double amount of N (3·0 cwt N/year—0·75 cwt N/acre per cut) was worthwhile only from 1 May to 30 August. Before and after then, yields were never larger and often smaller from it than from the single amount (0·375 cwt N/acre per cut). (Widdowson, Penny and Flint)



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### Liming programmes on Rothamsted and Woburn Farms

In 1966 a seven-year rotation of crops was introduced at Rothamsted and mainly a six-year one at Woburn. From 1966–68 the soils from fields within these rotations were sampled, on an 'acre plot' basis, to check pH. Of 274 acres sampled at Rothamsted, 106 had mean pH values below 6·5 and 46 below 6·0. Of 118 acres sampled at Scout Farm 29 had a pH below 6·5 even though all these fields were given 3 tons/acre of ground Chalk in 1966. At Woburn, of 102 acres sampled, 80 were more acid than pH 6·5 and 25 more than pH 6·0, so that a quarter of the acreage there urgently needed lime. Corrective dressings have been given and soil samples taken since from 81 acres at Rothamsted and 83 at Woburn showed none more acid than 6·0 at Rothamsted, and only one at Woburn. In future 3 tons/acre of ground Chalk will be applied every 7 years at Rothamsted and 3 tons of Dolomitic limestone every 6 years to the light land at Woburn. (Widdowson and Flint)

### Effects of phosphorus and potassium fertilising on yield of barley and severity of take-all disease

An experiment started in 1967 (and intended to last at least 6 years) measures the residual and cumulative effects of superphosphate on yields and severity of take-all in continuous barley grown with two amounts of potassium. The site on West Barnfield II grew winter wheat in 1967, grass between 1964 and 1966 and cereals each year from 1960–63. Phosphate is tested at none, 0·3 and 1·2 cwt $P_2O_5$/acre annually, and 1·8 and 7·2 cwt $P_2O_5$/acre applied only in 1967; potassium is tested at 0·3 and 1·2 cwt $K_2O$/acre broadcast before drilling. Maris Badger was grown in 1968 and 1969 with 0·8 cwt N/acre, and Julia in 1970 with 0·3, 0·6, 0·9 and 1·2 cwt N/acre tested on split plots. Unexpectedly there has been little take-all. Take-all was most prevalent each year on barley without phosphate fertiliser but, even so, the average percentage of diseased plants in July was only 2, 8 and 6 in 1968, 1969 and 1970 respectively, not enough to cause much loss of yield. Infection in May 1970 was:

| Cwt $P_2O_5$/acre | % plants with take-all |
|---|---|
| None | 19 |
| 0·3 annually | 7 |
| 1·2 annually | 4 |
| 1·8 in 1967 | 3 |
| 7·2 in 1967 | 1 |

The disease developed little during summer; indeed so few new roots became infected that in July infection was less than in May. We cannot explain the slow increase of take-all where cereals have often been grown.

**TABLE 6**

*Effects of K-manuring on yields of barley grain and straw and exchangeable K in soils on West Barnfield II, 1968–70*

(Means of all N and P treatments)

| K manuring (cwt $K_2O$/acre) | Grain*, cwt/acre | | | | Straw*, cwt/acre | | | | Exchangeable K in soil, ppm | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1968 | 1969 | 1970 | Mean | 1968 | 1969 | 1970 | Mean | 1968 | 1970 |
| 0·30 | 33·2 | 40·9 | 33·0 | 35·7 | 35·2 | 35·1 | 12·3 | 27·5 | 72 | 78 |
| 1·20 | 32·1 | 41·1 | 33·8 | 35·7 | 37·9 | 36·9 | 14·8 | 29·9 | 87 | 109 |
| S.E. | ±0·28 | ±0·36 | ±0·43 | — | ±0·75 | ±0·51 | ±0·32 | — | — | — |

* At 85% dry matter



https://doi.org/10.23637/ERADOC-1-125 

Table 6 shows how K altered yields of barley grain and straw and exchangeable K in the soils between 1968 and 1970. The larger dressing decreased grain yields in 1968 when the crop lodged badly in July. (Lodging was most severe on plots given both 1·2 cwt $K_2O$/acre in 1968 and 7·2 cwt $P_2O_5$/acre in 1967.) Extra K increased grain (by 0·8 cwt/acre) in 1970 but not in 1969; each year it increased straw by about 2 cwt/acre. Potassium has had negligible effects on incidence of take-all.

**TABLE 7**

*Effects of cumulative and residual dressings of superphosphate on yields of barley grain and total dry matter and $NaHCO_3$-soluble P in soils on West Barnfield II, 1968–70*

(means of all N and K treatments)

| P manuring (cwt $P_2O_5$/acre) | Grain*, cwt/acre | | | | Total dry matter, cwt/acre | | | | $NaHCO_3$-soluble P in soil, ppm | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1968 | 1969 | 1970 | Mean | 1968 | 1969 | 1970 | Mean | 1968 | 1970 |
| None | 30·0 | 34·5 | 24·5 | 29·7 | 50·6 | 50·8 | 29·3 | 43·6 | 6 | 6 |
| 0·3 annually | 35·3 | 42·0 | 32·2 | 36·5 | 60·2 | 64·8 | 38·1 | 54·4 | 7 | 8 |
| 1·2 annually | 32·7 | 42·9 | 38·3 | 38·0 | 60·4 | 72·0 | 46·4 | 59·6 | 13 | 22 |
| 1·8 in 1967 | 32·1 | 43·1 | 33·0 | 36·1 | 59·2 | 67·7 | 39·2 | 55·4 | 16 | 11 |
| 7·2 in 1967 | 33·2 | 42·5 | 39·0 | 38·2 | 63·8 | 72·0 | 46·4 | 60·7 | 54 | 36 |
| Mean | 32·7 | 41·0 | 33·4 | 35·7 | 58·8 | 65·5 | 39·9 | 54·7 | — | — |

* At 85% dry matter

Table 7 shows that superphosphate significantly increased yields in all years, whether applied cumulatively or as single dressings in 1967. The relative value of cumulative and residual dressings differed in different years. In 1968, when the crop lodged severely, yields were largest with 0·3 cwt $P_2O_5$/acre broadcast before sowing. In 1969, all four P treatments gave the same yield, whereas in 1970, with a long dry spell, yields with the larger amounts (1·2 cwt $P_2O_5$/acre/year or 7·2 cwt $P_2O_5$/acre in 1967) were about 6 cwt/acre more than with smaller amounts. Mean yields over three years were larger, by 1·5 to 2·1 cwt grain/acre, from the larger P dressings, whether given cumulatively or as a single dressing in 1967. (Mattingly, with Slope and Broom, Plant Pathology Department)

### Effects of soil phosphorus on barley yields

An experiment at Rothamsted, Woburn and Saxmundham measures the effects of previous dressings of superphosphate on barley yields. Maris Badger was grown in 1968 and 1969 at Rothamsted and Woburn, Zephyr (1968) and Sultan (1969) at Saxmundham; Julia was grown everywhere in 1970. Details of cropping sequences and manuring were:

| Experiment | Cropping sequence | Manuring (cwt/acre) N | Manuring (cwt/acre) $K_2O$ |
|---|---|---|---|
| Residual P rotation Rothamsted | Potatoes–barley–swedes in rotation | 0·4 –0·8 | 0·5–1·0 |
| Long-term phosphate Woburn | Barley after potatoes or fallow | 1·2 | 0·5 |
| Rotation II Saxmundham | Barley after sugar beet or turnips (1968), after barley (1969) or after sugar beet or potatoes (1970) | 0·75–1·0 | 0·5–0·6 |

Table 8 gives only yields and soil analyses from plots not given fresh superphosphate at sowing. Amounts of P soluble in 0·5*M* $NaHCO_3$, measured in soil samples taken two or three times between autumn 1967 and spring 1970, were used to calculate linear



https://doi.org/10.23637/ERADOC-1-125 

TABLE 8

*Mean yields of barley (grain and total dry matter), mean 0·5M $NaHCO_3$-soluble P in soil and mean increases in yields, 1968–70*

| Experiment | Mean yields, cwt/acre | | $NaHCO_3$-soluble P, ppm | | Increase in yields, cwt/acre/ppm $NaHCO_3$-soluble P | |
|---|---|---|---|---|---|---|
| | Grain* | Total dry matter | Mean (ppm) | Range (ppm) | Grain* | Total dry matter |
| Residual P Rotation, Rothamsted | 32·3 | 51·9 | 24·5 | 10–52 | +0·07 (±0·049) | +0·26 (±0·071) |
| Long-term phosphate, Woburn | 29·8 | 45·6 | 25·7 | 15–40 | +0·13 (±0·036) | +0·25 (±0·104) |
| Rotation II, Saxmundham | 33·1 | 49·4 | 32·3 | 7–56 | +0·12 (±0·036) | +0·23 (±0·067) |

* At 85% dry matter

regressions of grain yield and total dry matter on soluble P in the soil. The mean yield (19·5 cwt grain/acre) and $NaHCO_3$—soluble P (4 ppm) from treatment 1 on Rotation II at Saxmundham, which has never received P fertilisers, are both omitted because the line relating yield and soluble P is curved below 8–10 ppm. An increase of 1 ppm in $NaHCO_3$-soluble P increased grain yields at Saxmundham by 0·12 and at Woburn by 0·13 cwt/acre but by only 0·07 at Rothamsted. Increases at Rothamsted were smaller because in 1968 the crop lodged on plots given large dressings of superphosphate and yielded poorly (24 to 31 cwt/acre). Increases in total dry matter (0·23 to 0·26 cwt/acre/ppm $NaHCO_3$-soluble P) were similar on the three farms.

Percentages of total variance in mean grain yields, and total dry matter, accounted for by linear regression on $NaHCO_3$-soluble P were:

| | Percentage variance accounted for in | |
|---|---|---|
| | Grain | Total dry matter |
| Rothamsted | 15 | 71 |
| Woburn | 76 | 55 |
| Saxmundham | 62 | 63 |

Except for grain yield at Rothamsted, $NaHCO_3$-soluble P accounts for between one-half and three-quarters of the variance in mean yields of barley in these experiments.

The mean increase in yield from residues of superphosphate is about 0·11 cwt grain/ppm $NaHCO_3$-soluble P at a mean $NaHCO_3$-soluble P of 28 ppm. This rate of increase is about half that previously measured with Proctor barley at Rothamsted (+0·22 ±0·08 cwt/acre/ppm P) on soils with a mean $NaHCO_3$-soluble P content of only 13 ppm (*Rothamsted Report for 1967*, 47). Results are too few to assess the curvature of the response to soluble soil P reliably, but on soils containing less than 10 ppm $NaHCO_3$-soluble P responses are larger than those quoted here. (Mattingly)

**Contribution of soil P to barley yields.** The amount of P in soils at Woburn and Saxmundham that is soluble in 0·5*M* $NaHCO_3$ increases by about one-quarter of the net gain in total P from continued manuring (*Rothamsted Report for 1969*, Part 1, 60; *for 1969*, Part 2, 109). This knowledge, together with estimates of the probable net increase in total P in soils from current manuring, can be used to estimate the contribution P residues make to national barley yields.

Current recommendations for barley (*NAAS Advisory Paper* No. 4) are between 33 and 67 lb $P_2O_5$/acre, the mean is equal to 22 lb P/acre. At Rothamsted and Saxmundham,



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grain and straw together remove about 12–14 lb P/acre, so the net gain is 8–10 lb P/acre/year. This represents an accumulation of 120–150 lb P during 15 years and a quarter (about 30–40 lb P/acre) of this increase is bicarbonate-soluble P. Assuming an acre of ploughed soil weighs between 2 and $3 \times 10^6$ lb, the net gain in bicarbonate-soluble P from current cereal manuring should be between 10 and 20 ppm after 15 years, which should increase grain yields by 1·5 to 3·0 cwt/acre. During the 15 years between 1946–50 and 1961–65, average barley yields in England and Wales increased from 18·5 to 26·5 cwt/acre. Much of this increase came from new varieties, better weed control and the increased use of nitrogen, but the estimated gain in soil P could account for more than one-fifth. Where barley is grown in crop rotations that include heavily manured roots, which leave larger P residues, or where the soil initially contains very little P, the increases in bicarbonate-soluble P, and in potential barley yields, would be larger than this. (Mattingly)

## Anomalous phosphate response curves in tropical soils

The acid, severely weathered, ferrallitic soils in East Africa supply too little phosphorus for crops to yield well, but some need very large dressings of superphosphate to increase yields greatly. This is so at Namulonge (Uganda), where 62·5 or 125 kg/ha of triple superphosphate decreased yields of cotton and beans, whereas 2000 kg/ha increased them (Le Mare (1968) *J. agric. Sci., Camb.* **70**, 271–279). Reasons for this were sought, to find ways to make phosphate fertilisers more effective, as peasant farmers cannot afford such large dressings. Response curves in which yields decrease with the initial dressings seem characteristic of mono-calcium phosphate (MCP) (the active constituent of superphosphate), and may reflect the changes it undergoes in the soil. In moist soil, MCP hydrolyses to form dicalcium phosphate, which does not move, and an acid (pH 1·0–1·5) solution containing Ca and P, which moves in the soil by capillarity and dissolves soil constituents. The concentrations of aluminium, iron, manganese and other elements in solution increase, giving more to react with phosphate and for uptake by plants. Three soils from Namulonge are being used to study the relative importance of these various factors on plant growth: Soil 1 was from under natural vegetation; the others had been cropped for 20 years, and whereas Soil 2 has recently received lime, manure and fertiliser Soil 3 has not. Other characteristics were:

| Soil | pH in 0·01*M* $CaCl_2$ | Labile P ppm | P soluble in 0·5*M* $NaHCO_3$, ppm |
|---|---|---|---|
| 1 | 5·75 | 94 | 6 |
| 2 | 6·00 | 132 | 13 |
| 3 | 5·80 | 56 | 4 |

Five amounts of MCP supplying from 0 to 20 ppm P in the soil were tested by growing ryegrass in pots. The MCP (0 to 16 mg in 200 g soil) was placed in the soil as crystals in units of 4 mg. MCP increased dry matter yields linearly in Soils 1 and 3 but had no effect in Soil 2. Manganese concentration in the second cut of ryegrass grown on Soils 1 and 3 increased linearly from 375 to 420 ppm (in dry matter) over the range of MCP tested but was constant (290 ppm) in the crop from Soil 2. Hence the unfertilised soils contained more available manganese and small increments of MCP increased the amount of manganese taken up by the grass from them. The larger manganese concentration did not harm ryegrass, but other crops may be more sensitive.

A simple method was devised for placing separately in the soil the two products of hydrolysis of a single granule of superphosphate so their effects can be studied inde-



https://doi.org/10.23637/ERADOC-1-125 

pendently. The amount of dicalcium phosphate residue remaining at the site where MCP was placed, and the distance Mn and P moved in solution in a soil column, agreed well with results of TVA workers (Huffman (1962) *Proc. Fertil. Soc.* No. 71, 48 pp.) who first demonstrated how MCP behaved chemically in soil. (Le Mare)

### Experiments with magnesium

**Forms of Mg fertilisers.** An experiment on acid, magnesium-deficient, soil at Woburn tested the cumulative effects during three years of different forms of magnesium fertiliser on sugar beet (1968), potatoes (1969) and spring wheat (1970). Dolomitic limestone ($CaCO_3.MgCO_3$), calcined magnesite ($MgO$), and epsom salt ($MgSO_4.7H_2O$) were used to supply 100 or 200 lb Mg/acre annually. Calcitic limestone ($CaCO_3$) equivalent in Neutralising Value to the dolomite was also included.

**Crop yields and composition.** Table 9 shows that the materials increased sugar yields as much through their liming effects as their magnesium contents (although magnesium sulphate increased yields without affecting soil pH). Calcined magnesite was less effective than dolomite or epsom salt, probably because it affected soil pH less. Magnesium concentrations in the sugar-beet tops were increased as much by magnesite as dolomite, but less than by the more soluble epsom salt. Tops and roots of plants from untreated plots contained less Mg than other experiments show is needed for full growth. The increase of 14 cwt/acre of sugar from calcitic limestone showed the site to be too acid (pH 5·1) to grow sugar beet satisfactorily.

**TABLE 9**

*Effects of different forms of magnesium fertiliser and liming on yields of sugar, potatoes and spring wheat at Woburn*

| Treatment | lb/acre Mg | Limestone equivalent in N.V. cwt/acre | Crop yields: 1968 Sugar cwt/acre | Crop yields: 1969 Potatoes tons/acre | Crop yields: 1970 Wheat cwt/acre | Soil pH ($CaCl_2$) Sept. 1970 | Exch Mg ppm Sept. 1970 |
|---|---|---|---|---|---|---|---|
| Control | 0 | 0 | 24·1 | 9·7 | 11·0 | 5·1 | 17 |
| Ca-Lime | 0 | 15·0 | 38·3 | 11·2 | 6·9 | 6·6 | 17 |
| Ca–Lime + Mg–Lime | 100 | 15·2 | 42·4 | 12·5 | 11·2 | 6·3 | 52 |
| Mg–Lime | 200 | 15·4 | 44·1 | 11·8 | 9·9 | 6·1 | 105 |
| Ca–Lime + $MgSO_4.7H_2O$ | 100 | 15·0 | 43·6 | 12·1 | 11·6 | 6·7 | 98 |
| $MgSO_4.7H_2O$ | 100 | — | 32·1 | 10·5 | 11·3 | 5·1 | 98 |
| MgO | 100 | 3·8 | 32·9 | 10·2 | 10·0 | 5·6 | 62 |
| MgO | 200 | 7·5 | 40·2 | 10·4 | 9·4 | 5·9 | 107 |
| | | S.E. | ±1·99 | ±0·65 | ±1·61 | — | — |

Potatoes responded similarly to sugar beet, but the only statistically significant yield increases were from dolomite (both amounts) and limestone plus epsom salt. Magnesium in the tubers was increased from 0·08 to 0·10% by the most effective treatments.

The spring wheat was extremely poor, averaging only 10·2 cwt/acre of grain and 6·4 cwt/acre of straw. Many other spring cereals at Woburn yielded poorly because of the drought in 1970, and this experiment probably suffered more than others because it was on a sloping site with much surface run-off. The treatments did not affect yields.

**Soil composition.** Cations exchangeable with ammonium acetate and pH were measured each year in soil from each plot. Changes in exchangeable Mg were close to those expected (with a 9 in. ploughed layer) from the additions of epsom salt, but only half with magne-



*https://doi.org/10.23637/ERADOC-1-125* 

site and dolomite. Calcitic limestone increased exchangeable Ca about 70% of theoretical, but dolomite by only 40%. This suggests that dolomite reacted with the soil more slowly than limestone, and the pH measurements confirmed this, limestone increasing it to 6·6 and dolomite to 6·1; a mixture of equal amounts of limestone and dolomite, with equivalent neutralising value, increased it to pH 6·3.

All the magnesium fertilisers increased exchangeable Mg from the initial small value of 15 ppm to more than the 40 ppm, which is considered adequate for most crops. (Bolton)

**Magnesium exchange isotherms.** Graphs relating changes in amounts of Mg adsorbed by soils when equilibrated with 0·01*M* solutions containing different proportions of Mg and Ca, and the concentration ratio Mg/(Ca + Mg) in solution (*Q*/*I* curves), were linear for all soils tested. When extrapolated to zero Mg concentration in solution, intersects on the *Q* axis were less than amounts of Mg exchangeable by *N* ammonium acetate. Several further equilibrations for one hour with fresh 0·01*M* $CaCl_2$ failed to extract more Mg than predicted by linear extrapolation of the *Q*/*I* graphs. However, one soil (Saxmundham) that was kept for five months in several changes of $CaCl_2$ released slightly more Mg than expected, but only when there was less than 0·7 ppm Mg in the solution. The small amounts of extra Mg extracted by ammonium acetate cannot be explained without further experiments. All the soils adsorbed slightly more Ca than Mg relative to the concentrations in solution; Salmon (*J. Soil Sci.* (1964), **15**, 273–283) showed this could be caused by soil organic matter.

Liming increased the slopes of magnesium *Q*/*I* graphs, showing that concentrations of magnesium, as of potassium, in soil solutions, are lessened by liming. However, in many experiments, liming has increased Mg in crops, suggesting that it affects the physiology of Mg uptake. (Bolton)

## Effects of fertilisers on the composition of crops

**Effects of Na and K fertilisers on ryegrass.** We reported last year (p. 55) that sodium could partially replace potassium as a nutrient for Italian ryegrass because it affected yields, protein-N and free amino acids similarly. Analysis of these grass samples for soluble carbohydrates (Table 10) shows that, with the smaller amount of N (40 ppm), potassium and sodium decreased the reducing sugars, increased the sucrose and had

**TABLE 10**

*Effects of nitrogen, potassium and sodium fertilisers on yields and percentage of soluble carbohydrates in the second cut of ryegrass*

| Fertiliser supplying (as ppm of weight of soil used) | | | | % in dry matter | | | |
|---|---|---|---|---|---|---|---|
| N | K | Na | D.M. yield g/pot | Reducing sugars | Sucrose | Fructosan | Total soluble carbo-hydrates |
| 40 | 0 | 0 | 3·94 | 3·5 | 2·8 | 18·8 | 25·1 |
| 40 | 120 | 0 | 4·37 | 2·7 | 3·3 | 19·2 | 25·2 |
| 40 | 0 | 70 | 3·85 | 2·6 | 3·7 | 19·2 | 25·5 |
| 40 | 120 | 70 | 4·23 | 2·2 | 4·4 | 19·6 | 26·2 |
| 160 | 0 | 0 | 6·19 | 5 7 | 2·5 | 0·5 | 8·7 |
| 160 | 120 | 0 | 9·92 | 8·5 | 4·9 | 7·1 | 20·5 |
| 160 | 0 | 70 | 8·80 | 8·4 | 4·9 | 3·5 | 16·8 |
| 160 | 120 | 70 | 10·84 | 6·7 | 4·7 | 14·3 | 25·7 |
| | | | S.E. | ±0·16 | ±0·13 | ±0·48 | — |



https://doi.org/10.23637/ERADOC-1-125 

little effect on the fructosan. With 160 ppm of N, sodium and potassium increased the content of all sugars, especially fructosan. Fructosan was increased more by potassium than by sodium. (Nowakowski and Bolton)

We reported in 1968 (pp. 52–53) how N and K fertilisers affected the percentage of protein-N and the amounts of individual free amino acids in Italian ryegrass grown in

**TABLE 11**

*Effects of nitrogen and potassium on yield, %K and protein-N in the second cut of Italian ryegrass*

| Fertiliser supplying (as ppm of weight of soil used) | | 1967 | | | 1969 | | |
|---|---|---|---|---|---|---|---|
| N | K | D.M. yield g/pot | %K in D.M. | Protein-N (expressed as % of total N) | D.M. yield g/pot | %K in D.M. | Protein-N (expressed as % of total N) |
| 40 | 0 | 3·45 | 0·51 | 85·1 | 4·27 | 1·37 | 94·3 |
| 40 | 60 | 5·04 | 0·91 | 88·1 | 4·53 | 1·99 | 94·0 |
| 40 | 120 | 5·73 | 1·52 | 89·6 | 4·65 | 2·42 | 93·9 |
| 40 | 240 | 6·03 | 2·79 | 89·7 | 5·03 | 3·32 | 93·6 |
| 80 | 0 | 4·34 | 0·45 | 79·5 | 7·12 | 0·96 | 92·2 |
| 80 | 60 | 7·18 | 0·53 | 85·1 | 7·92 | 1·20 | 92·7 |
| 80 | 120 | 9·14 | 0·76 | 88·4 | 8·45 | 1·63 | 92·7 |
| 80 | 240 | 10·48 | 1·68 | 89·1 | 8·83 | 2·55 | 93·6 |
| 160 | 0 | 4·72 | 0·47 | 63·6 | 7·68 | 0·64 | 82·0 |
| 160 | 60 | 9·27 | 0·43 | 78·7 | 9·87 | 0·74 | 86·9 |
| 160 | 120 | 11·01 | 0·60 | 86·9 | 10·39 | 0·89 | 89·7 |
| 160 | 240 | 14·67 | 1·08 | 89·9 | 12·50 | 1·53 | 91·9 |

**TABLE 12**

*Effect of magnesium on free amino acids, ammonia and nitrate concentrations in oats*

| | Without Mg | With Mg |
|---|---|---|
| | expressed as μg amino acid per 1·0 g dry matter | |
| Aspartic acid | 2189 | 272 |
| *Threonine | 3160 | 424 |
| Serine | 678 | 312 |
| Glutamic acid | 603 | 261 |
| Proline | 354 | 102 |
| Glycine | 143 | 97 |
| Alanine | 1510 | 598 |
| Valine | 576 | 249 |
| Cystine | 236 | — |
| iso-Leucine | 327 | 190 |
| Leucine | 494 | 326 |
| Tyrosine | 282 | 174 |
| Phenylalanine | 377 | 231 |
| Ethanolamine | 154 | 131 |
| 4-amino-n-butyric acid | 1900 | 904 |
| Lysine | 310 | 218 |
| **Histidine | 140 | 144 |
| Arginine | Trace | Trace |
| Glutamine | 4267 | 757 |
| Asparagine | 7686 | 895 |
| Ammonia (as $NH_4$) | 400 | 144 |
| Nitrate (as $NO_3$) | 484 | 225 |
| Protein N as % of total N | 79 | 84 |

* Asparagine resolves with threonine
** Histidine merges with an unidentifiable compound



https://doi.org/10.23637/ERADOC-1-125 

extremely K-deficient soil (the soil used for the pot experiment in 1967 was taken from beside the Reference Experiment at Woburn). The experiment was repeated in 1969 using soil from the same field but from a different site with similar exchangeable K. In contrast to 1967, where potassium increased the percentage of protein-N and decreased the free amino acid content with all three amounts of N given (40, 80 and 160 ppm), in 1969 it did this only with grass given most N (Table 11). (Nowakowski and Petts, with Byers, Biochemistry Department)

**Effects of Mg fertiliser on yield and chemical composition of oats.** Oats were grown in the glasshouse with or without added Mg (25 ppm of weight of soil used) in a sandy, acid podsol soil limed to pH 6·5 from Wareham containing only 3.5 ppm of exchangeable Mg. Each pot was given 100 ppm N as $(NH_4)_2SO_4$, 80 ppm K and 32 ppm P as $K_2HPO_4$.

Magnesium increased fresh yields of tops from 50 to 61 g/pot, doubled the amount of sucrose (4·3 to 8·4% of dry matter) and increased fructosan 7 times (0·9 to 6·4%); it decreased ammonium-N to a third, free amino acid to a quarter and nitrate to a half (Table 12). An unusual feature of the amino acid analyses was the lack of arginine. (Glebowski, Nowakowski and Petts)

## Cations in soils

**Movement of potassium to ryegrass roots.** Three mechanisms by which nutrients move in the soil to roots (diffusion, mass-flow and root interception) were evaluated by growing perennial ryegrass in the glasshouse in pots containing Rothamsted (Geescroft, flinty silt loam) and Woburn (Butt Close, sandy loam) soils at 75% of their water-holding capacity without and with added K (to give about 10% K saturation). During growth, water was added *on* the soil surface. Without K, the grass took up more water from the Rothamsted than the Woburn soil and produced more dry matter but it took up similar amounts of K from both. K and water uptakes, and the equilibrium K concentration in the soil solution, were measured at intervals up to 276 days after germination by the 'take-down' method. Without K, mass flow accounted for one-sixth and one-third of the K taken up from Rothamsted and Woburn soil respectively. Except at first, diffusion probably accounted for the remaining uptake, but was the rate-controlling step for uptake from the Woburn soil only. With added K, mass flow was dominant in both soils and carried more than enough K to account for the measured uptake, suggesting increasing K-accumulation near the root-soil interface. Root interception probably did not contribute to K uptake except at first, because small pots were used; it may be more important in the field.

This experiment was designed to simulate in the glasshouse, conditions in the field where intermittent rain and broadcast and placed granular K fertilisers disturb smooth K concentration gradients near roots. Our results suggest that mass flow accounts for most of the K uptake from fertilised soils. (Addiscott and Talibudeen)

**The effect of cropping system on the exchange behaviour of K in soil.** Last year (p. 63) we reported that for each Classical experiment at Rothamsted, *Q/I* curves for soils from different manuring treatments were superimposable. Curves for Broadbalk and Hoosfield soils, both growing cereals, were superimposable but differed from the curve for Barnfield soil. Barnfield is on a different phase of the Batcombe series from Broadbalk and Hoosfield, and has grown root crops since 1843. To examine the effect of cropping, the potassium *Q/I* relationships for soils from all cropping sequences of the Rothamsted Ley–Arable experiments were measured. Contrasted in these two experiments, started



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in 1949, are plots in grass that have been in grass at least 100 years and plots in continuous arable on soils that have long been in arable. Between these extremes are soils on which 3-year leys have alternated with 3 years of arable cropping, both after old grass and old arable.

The $Q/I$ curves for soils from all treatments were superimposable on each other and on curves for soil samples taken 11 years earlier. Addiscott (*J. agric. Sci., Camb.* (1970), **75**, 451) has also shown that the $Q/I$ curves for samples of soil taken from Broadbalk plots in 1865, 1893, 1914, 1936 and 1966–67, were superimposable for soils with and without K manuring.

Thus, the $Q/I$ relationship for neutral and calcareous Rothamsted soils, on the same phase of one soil series, is not affected by time, by K from residues of K manures, by K depletion on plots unmanured for more than 100 years, or by cropping systems as different as continuous grass or continuous arable. However, the shape of the curve differs between soils from different soil series. (Addiscott and Johnston)

**Assessing the K status of soils.** Various chemical methods of estimating K in soil were compared with the K taken up by ryegrass, grown in the glasshouse, from soils of plots at Rothamsted and Woburn with contrasted manuring and cropping histories.

Potassium uptakes from soils of the Classical experiments were in the order: FYM + PK (Barnfield only) > FYM > PK > unmanured. From Broadbalk and Hoosfield soils given the same K-fertilisers, the K uptakes were very similar.

In the Rothamsted Ley–Arable experiments K manuring has differed according to the cropping sequence, except that grass leys given N get the same amount of K as grass–clover leys. Ryegrass grown in the pots took up most K from soils under continuous grass, and more from the soil under the clover–grass management than from soil under 'grass-with-N' management (these soils released about the same amount of K as soils from the Classical experiments manured with K fertiliser). Less was taken from the soils in ley and arable rotations than from under continuous grass. Soil from the 3-year grass–clover followed by 3-year arable sequence yielded slightly more K than soils under lucerne or grass-with-N sequences, or all-arable cropping.

In the Woburn Ley–Arable experiments attempts were made to bring the soils in the field to the same K status by adding different amounts of K at the end of each 3-year treatment sequence. Soils used in the pot experiments were taken during the first test-crop year, and cumulative K uptakes were much the same from soils having all treatments. Thus, the K status has been successfully balanced, and with these soils that differ little in their content of soil organic matter, the K had remained equally available after all treatment sequences.

The following measurements were made on the soils: (1) K exchangeable to ammonium acetate; (2) amount of K removed before the K potential fell to −5600 cal/eq. (*Rothamsted Report for 1969*, 63–64); (3) equilibrium activity ratio; (4) equilibrium K potential; (5) K buffer capacity, the tangent to the $Q/I$ curve at the point where the soil neither gains nor loses K. Results by methods 1 and 2 were closely correlated ($r = 0{\cdot}989$ for Rothamsted and Woburn soils together). Both these measurements of quantity of K related very well (better than activity ratios or K potentials) to cumulative K uptake by the ryegrass, even when the soils were stressed much more than would be usual in the field. Thus, except for soils that release K much faster than the Rothamsted and Woburn soils, single quantity measurements, such as exchangeable K, are adequate to give advice on K availability. We did not test fresh dressings of K to the ryegrass in pots, so cannot say whether these measurements would fullv predict response to fresh dressings in the field. (Addiscott and Johnston)



https://doi.org/10.23637/ERADOC-1-125 

## Concentration and distribution of nutrient ions in potatoes

The large dressings of K-fertiliser usually given to potatoes alter the uptake and distribution of other nutrients, especially those not given in fertilisers; these effects are important in attempting to increase yields and to improve quality. Potato tubers are 'dominant' or 'active' sinks for photosynthate and ions, so their needs influence the interaction of K with other nutrients. In a glasshouse experiment to see how fertiliser-K affects the uptake of K and other ions, the tops of the plants were removed just above the soil surface, and ions were measured in the sap that exuded from the stems and in various parts of the plants.

**Concentrations.** Adding K to the soil: (i) increased concentration of K in sap (and in all parts of the plants); (ii) decreased calcium concentration in the sap; (iii) had little effect on Mg in sap. The sum of the concentrations of K + Ca + Mg + Na in the exuded sap was proportional to the sum of the nitrate and phosphate concentrations.

**Distribution of ions.** Fertiliser K increased %K in tuber dry matter and %Mg was directly proportional to %K. Because K fertiliser also increased yield, the total magnesium needed by the tubers increased as the potassium supplied increased, which caused %Mg and *amount* of Mg in leaves and stems to diminish rapidly. With fertiliser-K, concentrations, and total amounts, of Ca in leaves and stems were less, but not in roots or tubers. Potassium had little effect on the distribution of phosphorus.

A second experiment measured the effects of combinations of K-fertiliser (applied to the soil) and Mg-fertiliser (applied to the soil, *or* sprayed on the leaves) on uptake and distribution of these and other ions. Again the Mg needed by tubers diminished the amounts found in leaves and stems. The distribution of magnesium in the plant was altered just as much by giving potassium as by giving magnesium. The converse was not true; Mg did alter the distribution of K, but less than K altered Mg distribution. Giving magnesium did not alter %K in tubers, but it increased yield and so increased the amount of K taken up. Magnesium applied to the leaves increased %Mg in tubers (showing this element can move *downwards* in the plant), but by less than Mg applied to soil. The main 'resistance' to downward movement of Mg seemed to be in the petioles. Potassium and magnesium together increased yields of tubers much more than either alone (K had the larger effect). Except without potassium, Mg increased the percentage of dry matter in the tubers; much K without Mg decreased it.

There was no evidence that potassium decreased the absorption of any nutrient except calcium; concentration of Ca in sap and total uptake were both diminished. The %Mg in leaves was less because the tubers took so much. Foliar analysis used to diagnose deficiencies does not distinguish between effects of uptake and distribution of a nutrient within the plant; plant analysis can be used reliably to assess nutritional status only when ion distributions and interactions are fully understood. The results of the second experiment suggest that when potatoes are given a lot of K they should on some soils also be given Mg-fertiliser, otherwise per cent dry matter may be small. (Addiscott)

## Micronutrients

**Soaking conifer seed in micronutrient solutions.** Gribkov (*Vest. sel'. Khoz. Nauki, Mosk.* (1960), No. 4, 129–131) reported improved germination in the laboratory, and increased growth of seedlings in the field, from soaking seed of several conifer species in solutions of micronutrients. We soaked seed of Sitka spruce (*Picea sitchensis*) from Washington



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State, for 18 hours at room temperature in Mn- and Cu-solutions (and in distilled water) before sowing them in pots containing a 1 : 2 (w/w) mixture of quartz and soil from Wareham Nursery (a podsol with very small nutrient reserves). All pots were given NPKMg. The solutions tested were: 0·1, 0·2, 0·4 g/l Cu (as $CuSO_4.5H_2O$) and 0·05, 0·1, 0·2 g/l Mn (as $MnSO_4.4H_2O$). The copper solutions increased Cu in seed from about 20 to 2000 ppm without affecting germination or growth. (The amounts given may have been too large.) The manganese solutions (Table 13), which increased Mn in seed by between 80 and 140%, did not affect germination or colour of crop, but increased seedling height by 13% and dry weight of tops by 23%; none or only trivial responses resulted from treating the seed with the most concentrated solution. Mn in the crop increased from 33 to 40 ppm in dry matter with increasing strength of solution. Sitka spruce seedlings grown in the nursery can contain from about 20 to more than 1000 ppm of Mn without showing signs of deficiency or excess, and it is surprising that growth was substantially increased by such small increases in concentration. These results may have practical implications for raising young conifers intensively as, for example, in plastic tubes. Because this method increases Mn in the crop without affecting the soil, it may help in understanding the benefits from partial sterilisation, in which manganese nutrition is one of the many factors involved. (Benzian, Mitchell and Smith, with Hill, Biochemistry Department)

**TABLE 13**

*Effect of soaking Sitka spruce seed in Mn-solution on the subsequent growth and Mn concentration of the seedlings*

| Seed soaked in solution containing Mn (g/l) | Mn in seed (ppm in dry matter) | Seedlings | | | |
|---|---|---|---|---|---|
| | | Height (cm) | Dry matter (mg/plant) Roots | Dry matter (mg/plant) Tops | Mn (ppm in dry matter) tops + roots |
| None | 808 | 7·9 | 174 | 324 | 32·6 |
| 0·05 | 1487 | 8·4 | 197 | 365 | 33·2 |
| 0·1 | 1720 | 8·9 | 195 | 397 | 37·2 |
| 0·2 | 1973 | 8·1 | 160 | 340 | 40·1 |
| S.E. | — | ±0·26 | ±12·6 | ±16·9 | ±1·10 |
| cv% | — | 6·4 | 14·0 | 9·6 | 6·2 |

**Boron deficiency in sugar beet at Woburn.** Two of the four blocks of sugar beet in the Woburn Organic Manuring experiment developed late symptoms of heart rot in 1969. In these two blocks few plants had symptoms where farmyard manure, peat, or straw had been applied during the previous four years; plots given PKMg fertilisers equivalent to the amounts of these nutrients applied in the farmyard manure had most affected plants.

Sample of leaves and crowns from each plot were analysed for boron. Table 14 shows that the percentages of roots with heart rot were small where boron exceeded 27 ppm in dry matter, but that more than half the roots were affected at 16 ppm B. The mean percentages of plants affected increased from 7 to 24, and the B content of leaves and crowns decreased from 26 to 21 ppm of dry matter, by increasing N applied as 'Nitro-Chalk' before drilling from 0·2 to 1·4 cwt/acre.

The site received ground chalk in February, and summer and autumn of 1969 were much drier than average. (Only 47 mm of rain fell in the 10 weeks before heart rot was estimated visually.) Boron deficiency in sugar beet is most common on light soils, such as at Woburn, and is increased by liming and drought.



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TABLE 14

*Percentage of sugar beet affected by heart rot and boron content of composite samples of leaves and crowns*

(Woburn Organic Manuring experiment, 1969)

| | % sugar beet affected by heart rot | Boron content of leaves and crowns (ppm in dry matter) |
|---|---|---|
| (a) Inorganic manuring (PKMg) equivalent to straw + superphosphate | | |
| Without organics | 16 | 23 |
| Straw (3 tons/acre/year) | 3 | 28 |
| Peat (3 tons/acre/year) | 0 | 30 |
| Green manures | 20 | 18 |
| (b) Inorganic manuring (PKMg) equivalent to farmyard manure | | |
| Without organics | 56 | 16 |
| Farmyard manure (20 tons/acre/year) | 1 | 27 |

The farmyard manure, peat and straw contain 23, 32 and 4 ppm of B in dry matter respectively and the total amounts applied between 1965 and 1968 were 0·9, 0·8 and 0·1 lb B/acre. However, whether the organic manures prevented heart rot primarily because they supplied small amounts of B, or by more complex effects on the solubility of soil boron, or by affecting soil moisture, is uncertain. (Chater and Mattingly, with Watson and Plumb, Plant Pathology Department)

## Experiments with herbicides

**Simazine and beans.** The effects of simazine on beans were again measured, testing new dressings and the residues of previous ones. Maximum yields were much smaller in 1969 because of the dry summer. On Barnfield even fresh simazine (1 lb/acre) decreased yields only a little on plots with FYM. Plots with P and K fertilisers only yielded very poorly, and fresh simazine decreased yield by one-third and residues by one-fifth. Both fresh simazine and residues have the greatest effects on the unmanured soil:

| | Yields of beans (cwt/acre) in 1970 | | |
|---|---|---|---|
| Annual manuring 1876–1970 | Without simazine | With fresh simazine | With simazine residues |
| None | 6·5 | 1·7 | 1·6 |
| P and K fertilisers | 8·9 | 6·1 | 7·6 |
| FYM (14 tons/acre) | 14·7 | 13·0 | 14·6 |

At Woburn the beans were drilled on 28 April after a very wet spell and before a very dry one. Simazine at 0·77 and 1·54 lb/acre was applied where 0·84 and 0·42 lb/acre were applied last year, and the residual effect of 1·68 lb/acre applied in 1969 was also tested. As in 1969, without simazine, soils with most organic matter yielded most grain, but whereas in 1969 the range was from 19·7 to 24·8 cwt/acre, this year it was from 11·1 to 18·3 (Table 15). Another contrast with 1969 was the lack of effect on yield of the larger amount of fresh simazine on the two soils with least organic matter. This was probably because rain after drilling was not enough to wash the simazine down to the roots. Slotted tubes were pushed into the plots before spraying and some removed in late June, others at harvest. Bioassays with ryegrass detected no simazine below 2 in. in June from



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TABLE 15

*Effect of fresh and residual dressings of simazine and soil organic matter on beans at Woburn in 1970*

| Simazine added lb/acre | | %C in air dry soil* | | | | |
|---|---|---|---|---|---|---|
| | | 0·66 | 0·74 | 1·15 | 1·55 | 2·28 |
| 1969 | 1970 | Yields of grain at 15% moisture content: cwt/acre | | | | |
| 0 | 0 | 11·1 | 10·7 | 13·9 | 17·8 | 18·3 |
| 1·68 | 0 | 7·4 | 7·3 | 13·7 | 15·5 | 13·2 |
| 0·42 | 1·54 | 10·4 | 10·2 | 15·9 | 15·8 | 14·3 |
| 0·84 | 0·77 | 4·7 | 6·1 | 11·7 | 14·4 | 16·6 |

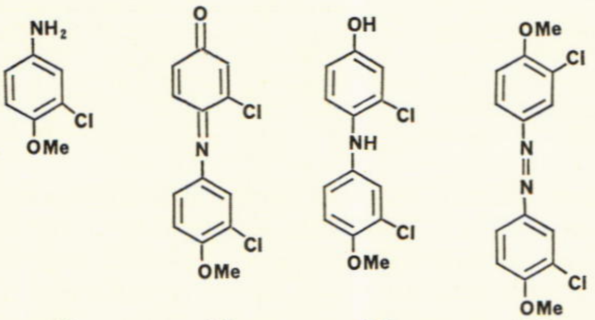
* Samples taken autumn 1968 0 to 12 in. deep, %C by Walkley-Black method multiplied by factor 1·3

the fresh dressing on the plots with least or most organic matter. By harvest simazine was detected in a band from 1·5 to 4·5 in. below the surface in soil from the plot with least organic matter and given the larger amount of simazine.

The other three soils, with increasing amounts of organic matter, yielded, on average, slightly less with than without simazine. Cultivations during autumn 1969 buried the residues of the simazine applied that spring, so they were in moist soil where roots grew in 1970. On the two soils with least organic matter, the residues of the 1·68 and 0·84 lb/acre dressings greatly decreased yields, more than by the larger amount of fresh simazine. On the soils richest in organic matter, simazine residues diminished mean yield by about 20%.

The beans that yielded least at Woburn had very immature straw, and whereas grain yield ranged from 5 to 18 cwt/acre, straw yields ranged only from 16 to 24 cwt. Plants affected by simazine early during the growing season later produced stems either without flowers or with flowers that did not set pods. Such late growth greatly delays combine harvesting. (Johnston and Briggs)

**Changes in aromatic amines in soil.** The ways aromatic amines break down in soils have been much studied since Bartha and Pramer (*Science* (1967), **156**, 1617) demonstrated that large amounts of propanil (3,4-dichloropropionanilide) in soil gave rise to tetrachloroazobenzene. We identified three dimeric products (II, III and IV) in soils treated with 3-chloro,4-methoxyaniline (I).




(I) (II) (III) (IV)

These products were detected only in soils containing more than about 5 ppm of the amine uniformly mixed. Metoxuron (N′-(3-chloro,4-methoxyphenyl) NN-dimethylurea) and its de-methylated derivatives break down too slowly in soils containing 20 ppm for either the amine or coupled products to be detected. I, II and III occurred after three



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weeks in soils treated with 25 ppm of 3-chloro,4-methoxyacetanilide or ethyl N-(3-chloro,4-methoxyphenyl) carbamate.

This work suggests that where aromatic amines, or derivatives that are rapidly degraded to the amine, are used in conditions that allow local concentrations in soil to exceed 5 ppm, coupled products may form. This agrees with the occurrence (Kearney *et al. Weeds* (1970), **18**, 464) of tetrachloroazobenzene in field soils treated with propanil but not with the corresponding urea derivative diuron, N′-(3,4-dichlorophenyl), NN-dimethylurea. (Briggs)

**Herbicides and liquid fertilisers combined.** It is obviously cheaper to apply solutions of fertilisers and herbicides mixed rather than separately. Equally obvious disadvantages are that the time chosen may be a compromise and not best for one or other of the chemicals (or for either); the type of spray jet and nozzle size used may also be a compromise between that best for killing weeds and the best for avoiding damage to the crop. Further, fertiliser solutions often damage ('scorch') leaves of crops, and this may be accentuated by herbicide in the solution. Solutions of urea and ammonium nitrate are used increasingly as top-dressings, so herbicide was added to them to see the effect on appearance, growth and yield of winter wheat, spring barley and permanent grass. The three experiments were at Rothamsted on soils derived from Clay-with-Flints over Chalk. Initial pH values (in 0·01$M$ $CaCl_2$) were 6·6 (wheat), 5·8 (barley) and 5·2 (grass); all crops had basal dressings of PK fertilisers.

***The liquid fertiliser***, made from urea and ammonium nitrate (26% N), was applied as a spray to supply 0·3, 0·6 and 0·9 cwt N/acre and compared with the same amounts of N applied as solid top-dressings of 'Nitro-Chalk' (21% N). The main treatments were all applied on the same day.

***The herbicide***, a mixture of dichlorprop plus MCPA (80 oz acid equivalent/gal was tested at 20, 40 and 60 oz a.e.) applied as 2, 4 and 6 pints per acre.

***Methods used.*** Small plots (4·5 ft × 7 ft) were sprayed at 15 lb/sq in. pressure by a small Oxford precision sprayer fitted with an Allman fan jet (size OO); with herbicide only (on 'Nitro-Chalk' plots), the liquid fertiliser only, or the combined herbicide and fertiliser. Each amount of herbicide given alone was applied in 30 gal/acre of water but volumes of the combined fertiliser and herbicide (10, 20 or 30 gal/acre) were determined by the amounts of fertiliser needed to supply the three amounts of N tested. Appropriate amounts of herbicide and fertiliser were measured for, and sprayed on, individual plots; mixtures of the two were made the day before spraying. 'Nitro-Chalk' was broadcast immediately after spraying herbicide. All main treatments were applied to wheat at growth stage **4** and to barley at growth stage 5. (E. C. Large (1954) Growth stages in cereals. *Pl. Path.* **3**, 128–129.)

**Winter wheat (Cappelle-Desprez).** Four days after spraying on 8 May the plants were scorched, the extent increasing with increasing amounts of herbicide; the effects were not altered by 'Nitro-Chalk' top-dressings. Scorch was much increased by liquid fertiliser applied with the herbicide, and was greatest with largest amounts of the two materials. Liquid fertiliser alone did not scorch and there was little on additional plots sprayed with herbicide 10 days after broadcasting 'Nitro-Chalk' (perhaps because the N had increased crop growth). On 14 May scorch had diminished and by 21 May had disappeared. Wheat



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with 'Nitro-Chalk' looked better than with liquid fertiliser, but with both types of fertilisers growth looked poorer with increasing amounts of herbicide. No treatment caused irregular growth or deformed ears.

***Weed growth*** was diminished by 74% by the largest herbicide dressing on 'Nitro-Chalk' plots and by 84% on liquid fertiliser plots.

***Yields.*** 'Nitro-Chalk' produced more grain than liquid fertiliser without herbicide and in eight of the nine comparisons with herbicide (Table 16). There was no evidence that herbicide diminished the effect of either of the N fertilisers on grain or straw.

Recorded yields of wheat—also of barley and grass—are affected by both the contrast between 'Nitro-Chalk' and liquid N fertiliser, and the interaction between fertilisers and herbicide.

**TABLE 16**

*Comparisons of solid N fertiliser and a separate herbicide spray with a spray combining N fertiliser and herbicide*

| | 'Nitro-Chalk' | | | Liquid N fertiliser | | |
|---|---|---|---|---|---|---|
| Cwt N/acre | 0·3 | 0·6 | 0·9 | 0·3 | 0·6 | 0·9 |
| Herbicide pints/acre | | | | | | |
| | *Winter wheat*, cwt/acre of grain (with 15% moisture) | | | | | |
| None | 44·1 | 49·0 | 50·6 | 40·8 | 44·4 | 46·8 |
| 2 | 43·4 | 43·5 | 45·5 | 37·5 | 41·5 | 48·5 |
| 4 | 43·6 | 43·5 | 47·6 | 39·0 | 40·4 | 42·0 |
| 6 | 41·8 | 44·7 | 48·0 | 33·6 | 40·7 | 44·5 |
| Standard error | | | ±1·89 | | | |
| c.v.% | | | 8·7 | | | |
| | *Spring barley*, cwt/acre of grain (with 15% moisture) | | | | | |
| None | 21·7 | 25·8 | 25·4 | 18·9 | 21·6 | 25·3 |
| 2 | 21·1 | 22·3 | 22·8 | 20·3 | 23·6 | 23·6 |
| 4 | 23·5 | 23·0 | 24·5 | 20·8 | 24·0 | 25·0 |
| 6 | 18·8 | 23·8 | 24·5 | 21·0 | 23·3 | 26·3 |
| Standard error | | | ±1·38 | | | |
| c.v.% | | | 12·0 | | | |
| | *Permanent grass*, cwt/acre of dry matter (total of two cuts) | | | | | |
| None | 53·8 | 58·9 | 57·8 | 48·0 | 52·2 | 51·6 |
| 2 | 54·2 | 48·8 | 55·0 | 47·9 | 47·6 | 49·3 |
| 4 | 44·4 | 49·2 | 54·5 | 43·8 | 50·3 | 47·0 |
| 6 | 49·3 | 49·1 | 47·5 | 39·3 | 45·8 | 50·3 |
| Standard error | | | ±2·54 | | | |
| c.v.% | | | 10·2 | | | |

**Spring barley (Julia),** sprayed on 28 May, showed scorch next day. Scorch was slight where solid N fertiliser was given but severe with liquid fertiliser and increased with increasing amounts of fertiliser and herbicide. The condition of the plots was similar on 5 June, but by 9 July evidence of damage by herbicide had disappeared.

***Weeds*** were controlled as well by the large amounts of herbicide as by hand-weeding. On 11 August (2 weeks before harvest) the smallest and largest quantities of herbicide lessened weeds by 60% and 75% respectively on the 'Nitro-Chalk' plots and by 66%



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and 99% on the liquid fertiliser plots. Neither the form nor amount of N affected weed growth with herbicide, but without it weeds were slightly more with more N.

*Score for weed control in barley on 11 August 1970*

0 = no weeds, 10 = most weeds observed

| Herbicide pints/acre | 'Nitro-Chalk' | Liquid N fertiliser |
|---|---|---|
| 0 | 6·7 | 5·9 |
| 2 | 2·8 | 2·0 |
| 4 | 2·5 | 0·9 |
| 6 | 1·6 | 0·2 |
| Handweeded (in spring) | 1·2 | — |

***Yields*** and responses to N were small because the summer was so dry. In most comparisons, yields of grain with 'Nitro-Chalk' were diminished slightly by herbicide, whereas with liquid fertiliser they were increased. Without herbicide, 'Nitro-Chalk' gave more grain than liquid fertiliser at each amount of N. With herbicide, results were more irregular, but liquid N gave larger yields in six out of nine comparisons. Straw yields were small and 'Nitro-Chalk' produced slightly more in most comparisons.

**Permanent grass.** The sward used (on Road Piece) was sown about 20 years ago and contained many species of annual and perennial broad-leaved weeds. Fertilisers and herbicide were applied on 19 May. Next day there was no damage to herbage from 'Nitro-Chalk' and herbicide, but some where liquid fertiliser was applied alone and most with the most N and the most herbicide.

***Weed control*** was affected by the fertiliser–herbicide combination used. On 20 May, herbicide had caused only slight damage to weed foliage on plots given 'Nitro-Chalk' but considerable damage on plots given liquid N.

***Yields*** were small because no rain fell after fertilisers were applied. The grass grew little and headed early so was cut on 16 June; there was no response to either form or amount of N. Yields were diminished by all except the smallest amounts of herbicide, presumably because the weeds were killed.

The treatments were repeated on 30 June because some weeds had persisted. There was little or no scorch because 0·24 in. of rain fell a few hours after spraying. By 12 August the two largest amounts of herbicide had decreased weeds by 85% on 'Nitro-Chalk' plots but by only 74% on the liquid N plots. Without herbicide there were more weeds on 'Nitro-Chalk' plots. Herbicide increased the proportion of fine-leaved grasses and there was no interaction with form of fertiliser.

Yields of the second cut were larger from 'Nitro-Chalk' than from liquid N in 11 out of 12 comparisons. Although the effects were irregular, yields tended to be larger without than with herbicide.

At the second (and final) cut on 15 October, the herbage from plots without herbicide contained many weeds, whereas that from plots with the two largest amounts of herbicide, with solid or liquid fertiliser, were almost weed-free.

**Conclusions.** In most comparisons, and for all crops, yields were larger with 'Nitro-Chalk' than with liquid fertiliser. The effectiveness of neither the liquid fertiliser, nor the herbicide was diminished by applying both together. If a liquid fertiliser is used, these pre-



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liminary results show no reason why it should not be applied together with herbicide; indeed, the herbicide may be more effective than when sprayed separately. Although all crops became scorched, sometimes severely, there was little evidence that it had a permanent effect or lessened yield; it may be an advantage by making weeds more susceptible to herbicide.

The effects of nutrients or herbicides applied as sprays—either alone or together—depend much on the weather at the time; so it would be unwise to draw general conclusions from results obtained in one very dry season. (Freeman)

## Apparatus and methods

**Amino acid analysis.** We acquired a Technicon Amino Acid AutoAnalyser (Model NC-1) in April; since June it has been used to measure the amino acids in the non-protein fractions of plants. Early problems cured or minimised were: oscillating baseline, negative blips and baseline drift. Each determination takes 21 hours and four are made each working week. The reproducibility of results for each amino acid found in 12 plant extracts determined over three months, given as the standard error of a single determination, expressed as a percentage of the mean value is: aspartic acid 15; serine 1; glutamic acid 18; proline 22; glycine 9; alanine 4; valine 4; isoleucine 5; leucine 2; tyrosine 12; phenylalanine 8; ethanolamine 7; 4-amino-n-butyric acid 3; lysine 2; histidine 11 and arginine 5.

These results are reasonable as duplicate runs were not always done on consecutive days, different batches of buffers, reagents, and standard samples, were used and laboratory temperatures differed. We use a sodium citrate buffer gradient system as recommended by Technicon and an eluting temperature of 60°C; unfortunately this does not allow glutamine and asparagine to be determined. At 60°C, glutamine is cyclised to pyrrolidone carboxylic acid, which does not react with ninhydrin, and asparagine resolves with threonine. The recirculating heating bath for the column jacket is being modified to operate the column at 35°C for the first 6½ hours and at 70°C for the remainder of the 21-hour chromatogram and a lithium citrate buffer system will be used as recommended by Perry *et al.* (*J. Chromatog.* (1968), **38**, 460–466). This should allow us to measure threonine also. (Petts and Nowakowski)

**Technicon AutoAnalyser.** The Dual Channel Technicon Flame Photometer was developed for measuring potassium and calcium simultaneously. The potassium values correlated well with those using an EEL flame photometer but calcium ones were at first very erratic. P interferes with Ca determinations but adding glycerol eliminates the effect of P concentration up to 30 $\mu$g/ml (Heeney *et al*, *Analyst* (1962), **87**, 49–52) when most values for Ca correlated well with those obtained with the SP900 spectrophotometer. Abnormal samples (such as those obtained by ashing Sitka spruce) still give poor correlation, possibly because aluminium and manganese interfere.

A single digested sample is now used in the AutoAnalyser system to determine calcium, potassium and phosphorus simultaneously. (Cosimini and Messer)

**Atomic absorption spectrophotometry.** The instrument built in 1964 was greatly improved to measure many trace elements in plant digests and soil extracts routinely without first concentrating them. The aerosol path from nebuliser to flame is vertical to diminish the loss of solids by collision with the walls of the instrument. A nebuliser with water-cooled capillary delivers test solution at 3 ml/minute into a tube furnace at 600°C that vaporises all the solution. To prevent excessive water vapour reaching the flame (which would slow the burning velocity of the combustible gases in the premixed cone, cool and



https://doi.org/10.23637/ERADOC-1-125 

dilute the atoms it contained) a water-cooled condenser is put above the furnace and removes about 40% of the water vapour from the aerosol. A 'T' burner with 4·5 cm internal diameter throat and barrel gives even distribution of aerosol to a 12 cm adjustable slot.

Without scale expansion and using town gas/air, 50% scale deflection is obtained with 0·025 ppm Mg, 0·25 ppm Mn, 0·30 ppm Cu, 0·15 ppm Zn and 0·08 ppm Cd. (Rawson)

**Automatic scintillation spectrometer.** The Beckman LS250 automatic scintillation spectrometer was installed in August and initial problems solved. The instrument has been calibrated for tritium, carbon 14 and calcium 45 and deals with liquid samples of radionuclides. It is especially useful for handling weak $\beta$ energy emitters, 'near-background' radioactivity, rapidly decaying emitters requiring 'elapsed time' recording, various degrees of chemical quench of the scintillation effect, and for experiments with 'double' and 'triple' labelling.

The automatic $\beta$–$\gamma$ spectrometer complements the Beckman instrument for solid samples; it can assay, with Geiger-Muller detectors, samples from 'single label' experiments with strong $\beta$ emitters, or, with scintillation detectors through a pulse height analyser, $\gamma$-emitters in 'multi-label' experiments. More than 6000 samples were analysed. (Elsmere and Talibudeen)

### Staff and visiting workers

F. G. Hamlyn left and G. Panther and Lucretia Scotland were appointed.

Visiting workers included Mrs. Anne Fenerty (USA), Dr. H. Glebowski (Poland), Mr. I. C. R. Holford (Australia), Mr. E. Pushparajah (Malaysia) and Dr. S. Sivasubramaniam (Ceylon).

G. W. Cooke took part in a Symposium in Moscow on 'Agrochemical research and the use of fertilisers'; this was the first symposium arranged by the V. I. Lenin All Union Academy of Agricultural Sciences and the Agricultural Research Council. He also attended the Ninth Congress of the International Potash Institute in France, as a guest of the Institute. O. Talibudeen visited research institutes in East Germany as a guest of VEB Kombinat Kali and Propane Fertilisers Limited.

S. Sivasubramaniam was awarded the Ph.D. degree of London University.



https://doi.org/10.23637/ERADOC-1-125 